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An integrated environment model for a constructed wetland – Hydrodynamics and transport processes

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ABSTRACT

Constructed wetlands (CW) have become a popular technology for treating urban and agricultural stormwater runoff. In South Florida, Stormwater Treatment Areas (STAs) have been built to reduce phosphorus (P) concentrations in runoff from agriculture and other sources, including Lake Okeechobee discharges, prior to delivery to the Everglades Protection Area. The scale of this constructed wetland project is unprecedented in terms of size, cost, and scientific challenges. Models/tools are needed to provide detailed spatial and temporal information to optimize the P removal efficiency and to predict the dynamic response of STAs under a variety of management conditions. The Lake Okeechobee Environment Model (LOEM) developed for Lake Okeechobee has been enhanced to simulate hydrodynamics and transport processes in the wetland environment. The flow resistance caused by Submerged Aquatic Vegetation (SAV) and Emergent Aquatic Vegetation (EAV) is included in the LOEM-CW. The LOEM-CW is calibrated and validated with 6 years of measured data (2008–2013) at different locations in STA-3/4 Cells 3A and 3B. Through graphic and statistical comparisons, it is shown that the model simulated stage, flow velocity, water temperature, and total suspended solid (TSS) in the study area reasonably well. The LOEM-CW is poised to serve as a powerful tool in wetland management and STA operation.

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1. Instruction

The Everglades, covering around 28,000 square kilometers in South Florida, is one of the largest tropical wetlands in the world (Fig. 1). In 1948, due to increasing anthropogenic activities, around 2830 square kilometers of land situated south of Lake Okeechobee (James et al., 1995) was designated as the Everglades Agricultural Area (EAA). As a consequence, much of the runoff through this area has been rerouted through drainage canals, altering local hydrodynamic properties. Agricultural activities, including use of crop fertilizer and raising livestock, has contributed to nutrient loading entering EAA runoff, which eventually discharges into the Everglades. Excessive nutrients entering the Everglades deteriorate the overall water quality and can cause eutrophication in the area (Chimney and Goforth, 2001; Havens et al., 1996). As a measure to prevent continuous deterioration of water quality due to nutrient loading, the South Florida Water Management District (SFWMD) developed constructed wetlands named Stormwater Treatment Areas (STAs) at the intersection between the EAA and the Everglades. Nearly 230 square kilometers, south of Lake Okeechobee, have already been converted to such wetlands. The main objective of these STAs is to treat stormwater runoff to reduce phosphorus loading to the Everglades (Juston et al., 2013; SFER, 2012, 2013).

As a part of their metabolic processes, plants within the wetland area uptake and store phosphorus within the plant cells (Newman et al., 1996), which eventually becomes partially retained by the sediment as the plants decay and sink to the bottom (Dierberg et al., 2005). The function of an STA is graphically displayed in Fig. 1. Due to this entrapment of primary nutrients by plants and sediment, significant nutrient reductions, TP retention of $76 \pm 11\%$ have been recorded (Chen et al., 2015); however such high removal rates are not always achievable due to variability in weather and runoff from tributary basins as well as heterogeneous hydraulic and hydrologic behaviors within the wetlands (Variano et al., 2009).

Treatment flow-ways within an STA are generally comprised of Emergent Aquatic Vegetation (EAV) such as cattail and bulrush near the inflow point and Submerged Aquatic Vegetation (SAV) near the outflow points of flow-ways. The vegetation within the STAs plays a vital role in the reduction of current velocity and wind-wave effects (Jin et al., 2000; Grant and Madsen, 1979; Ji and Jin,

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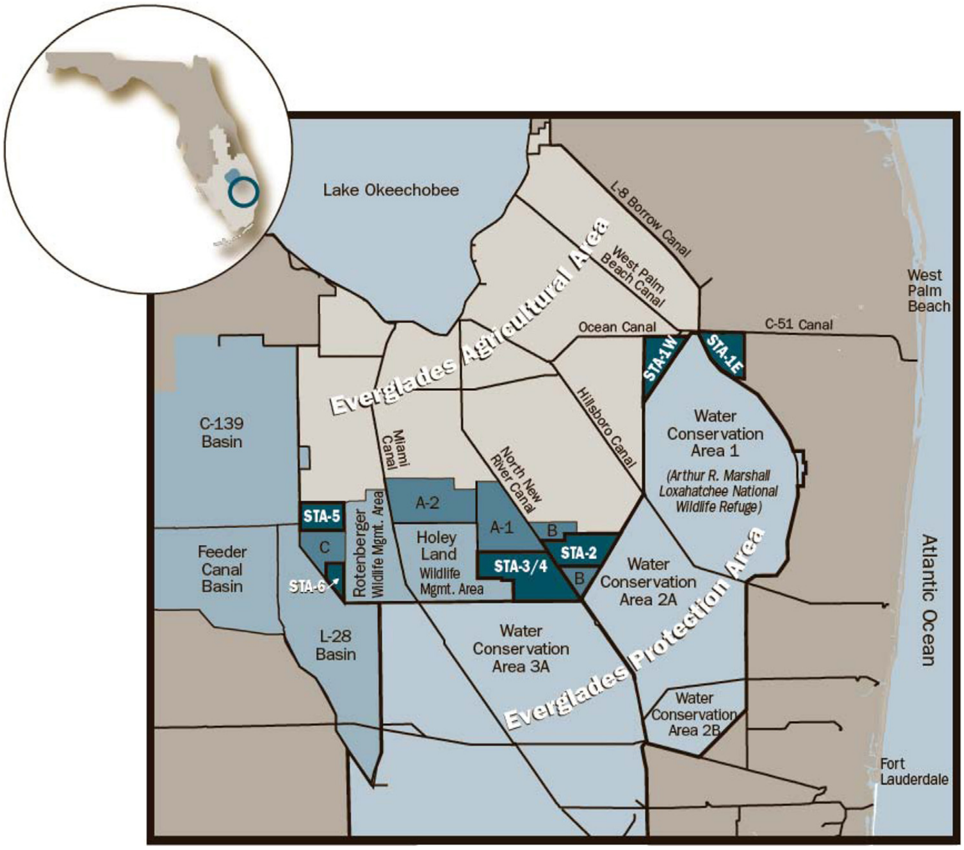

Fig. 1. Location of the Everglades and Stormwater Treatment Areas (STAs).

2006). Water levels within the STAs are generally below the top of the EAV vegetative canopy even during high water conditions. EAV strips have been incorporated into SAV areas to help stabilize submerged vegetation under high wind and/or high flow conditions. Under these conditions, the vegetation may dissipate some wind energy before it is transferred to the water body (Kemp and Simons, 1982). Submerged Aquatic Vegetation (SAV) and Emergent Aquatic Vegetation (EAV) also act to dissipate wave energies, resulting in significantly lower significant wave heights and wave setup (Ris, 1997; DB Environmental, 2002). The dense vegetation also reduces the effective storage within the STAs. Under a tropical storm condition, EAV and SAV (Chang and Jin, 2012) play more active roles in reducing energy in the water column. Water levels within the STAs is generally below the top of the EAV canopy even for high water conditions and EAV strips have been incorporated into SAV areas to help stabilize submerged vegetation under high wind or flow conditions. Under these conditions, the vegetation may dissipate some wind energy before it is transferred to the water body (Kemp and Simons, 1982). SAV and EAV also act to dissipate wave energies, resulting in significantly lower wave heights and wave setup (Ris, 1997; DB Environmental, 2002). The dense vegetation also reduces the effective storage within the STAs. Under a tropical storm condition, EAV and SAV (Chang and Jin, 2012) play more active roles in reducing energy in the water column.

EAV and SAV (Havens and Gawlik, 2005) are major components of the ecosystem and affect both critical habitat and water quality. EAV and SAV respond to water clarity, which is affected by the amount of nutrients, suspended solids and algae present in the water, and to water depth. Consequently, it is an important integrative performance measure for evaluating the overall health of an STA. Healthy submerged and emergent plant communities provide good habitat and water quality for wildlife and aquatic life in STAs. Periphyton growing on EAV and SAV (epiphytes) (Scheffer, 1998) and on the bottom sediments (epipelon) provide a food supply to higher trophic-level grazers (Rodusky, 2010; Rodusky et al., 2001; Havens et al., 2004) such as macro invertebrates and fish, and also sequester nutrients from the water column, thereby indirectly suppressing the potential for algal blooms to occur. Consequently, one of the long-term management goals is maintaining an optimal range of water depths in the STA to support healthy emergent aquatic vegetation communities, because of the role the plants play in removing nutrients from the water (Miao and Sklar, 1998) and in supporting the food web in this area.

A complete understanding of ecosystem processes and effects will require a careful integration of the results of water quality, SAV (Scheffer et al., 1994; Scheffer, 1989) and EAV monitoring, available experimental data, and outputs from a hydrodynamic, water quality, SAV, and EAV model. The previous model used for constructed wetland area is introduced by Lal et al. (2005) and SFWMD (2005). It is an overland model which does not apply the full hydrodynamic equations (Navier–Stokes equations) to calculate the current velocity and momentum exchange in the water column. In this study, the Lake Okeechobee Environment Model (LOEM) (Jin et al., 2000; Jin and Ji, 2001; Jin et al., 2002; Chang and Jin, 2012; Ji and Jin, 2014) is enhanced and applied to an STA to become a constructed wetland model (LOEM-CW). The model, after adding the vegetation stress terms in Navier–Stokes equations, provides detailed information regarding surface elevation, velocity current, circulation patterns, sediment resuspension and deposition, water quality, periphyton, and submerged aquatic vegetation (SAV) distribution

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